

Kinematic Study of the Blazar 0716+714

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Abstract. We determined the kinematics at the jet of 0716+714 from a re-analysis of multi-frequency VLBI data (5, 8.4, 15, 22 GHz) obtained during the last 10 years combined with data from the literature. For this intra-day variable blazar, only a lower limit of its distance is known ($z \geq 0.3$). We find that 0716+714 is a relatively fast superluminal source (with a Lorentz factor of $\gamma > 15$), revising earlier results showing much slower motions. We discuss the new findings with emphasis on the interpretation of the observed rapid radio variability.

1. Introduction

The BL Lac object 0716+714 is extremely variable on time-scales from hours to months at all observed wavelengths from radio to X-ray. The redshift of 0716+714 is not yet known. However, optical imaging of the underlying galaxy provides a lower limit to the distance of $z \geq 0.3$ (Wagner et al. 1996). In the radio bands 0716+714 shows intraday variability (IDV) (Witzel et al. 1986; Heeschen et al. 1987). It exhibits a very flat radio spectrum, extending up to at least 350 GHz. The variability appears to be correlated between radio and optical (Quirrenbach et al. 1991) and over wide ranges of the electromagnetic spectrum (Wagner et al. 1996). The simultaneous variations between X-ray, optical and radio strongly suggest an intrinsic origin for the variability. VLBI studies covering more than 20 years at 5 GHz show a core-dominated evolving jet extending to the north, with contradictory measurements of its proper motion ranging from 0.05 mas yr^{-1} to 1.1 mas yr^{-1} (Eckart et al. 1986, 1987; Witzel et al. 1988; Schalinski et al. 1992; Gabuzda et al. 1998; Tian et al. 2001; Jorstad et al. 2001).

Our analysis includes data at 5 GHz at four epochs from the CJF-Survey between 1992 and 1999 (Britzen et al. 1999) and a VSOP observation from 2000, data at 8.4 GHz at two epochs from astrometric observations (Ros et al. 2001) and three epochs of our own observations between 1994 and 1999, data at 15 GHz at five epochs from the VLBA 2 cm Survey from 1994 to 2001 (Kellermann et al. 1998, Zensus et al. 2002) and data at 22 GHz at seven epochs from Jorstad et al. (2001) and four epochs of our own data from 1992 to 1997. The observational details and the data reduction will be described in detail in Bach et al. (2003 in prep.). Examples of those are presented in Fig. 1.

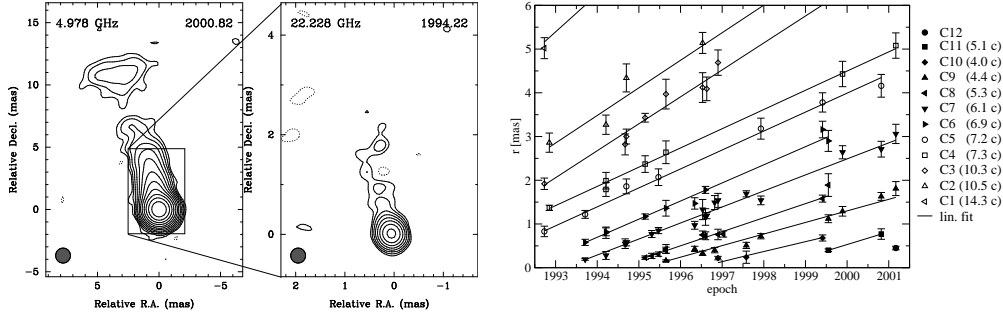


Figure 1. Left: Contour maps at 5 and 22 GHz at different epochs convolved with circular beams of 1.2 mas and 0.3 mas respectively. Right: The core distance of individual VLBI components derived from our model-fits at various frequencies are plotted against time. The solid lines are linear fits to the path of the components. The velocity derived from the fits are set in parenthesis behind the component labels in the legend.

2. Results and Discussion

To investigate the kinematics in the jet of 0716+714 we cross-identified individual model components along the jet using their distance from the VLBI core, flux density and size. To test the stability of the VLBI core position with time and between different frequencies we compared the core separations of the jet components of each epoch with respect to the adjacent observations, and we found no systematical position offsets. Supported by a graphical analysis, which is presented in Figure 1, we obtained a satisfactory identification scheme for the kinematics in the jet of 0716+714. This scenario consists of 11 superluminal components moving linearly away from the core.

2.1. The New Kinematical Model

The components in this scenario move with 0.3 mas yr^{-1} to 0.5 mas yr^{-1} in the inner part of the jet ($r \leq 3 \text{ mas}$) and with up to 0.8 mas yr^{-1} in the outer regions. Assuming $z = 0.3$ for 0716+714, the measured angular separation rates correspond to speeds of $4.0 c$ to $14.3 c$ (where we adopt $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and $q_0 = 0.5$). A previous preliminary analysis by Tian et al. (2001), who used only part of the data presented here, gave very similar speeds. The speeds found in this paper are lower than the $15 c$ to $20 c$ found by Jorstad et al. (2001), who observed the source only over a short time interval (3 yr). The difference between their and our result may be explained by slightly different (and unfortunately not unambiguous) map parameterizations using different Gaussian models. With an average apparent jet speed of about $7 c$ and possibly higher speeds to up to $20 c$, 0716+714 is considerably faster than a ‘typical’ BL Lac object, for which speeds of $\leq 5 c$ are regarded as normal (Gabuzda et al. 2000 and references therein).

2.2. Kinematics and Geometry

Using the measured motion of C3 ($10.3 c$ for $z = 0.3$), the fastest, well constrained component in our model, we can place limits on the kinematics and geometry of 0716+714. Adopting $\beta_{\text{app}} = \frac{\beta \sin \theta}{1 - \beta \cos \theta}$ we find for the jet viewing an-

gle θ , which maximizes the apparent speed a value of $\theta_{\max} = 5.6^\circ$. The minimum Lorentz factor $\gamma_{\min} = (1 + \beta_{\text{app}}^2)^{1/2}$ then is 10.3, which corresponds to a Doppler factor of $\delta = \gamma^{-1}(1 - \beta \cos \theta_{\max})^{-1} = [\gamma - \sqrt{\gamma^2 - 1} \cos \theta_{\max}]^{-1} = 10.3$. For smaller viewing angles the Doppler-factor increases and reaches its maximum of $\delta_{\max} = 2\gamma$ at $\theta \rightarrow 0$. For C3 this yields $\delta_{\max} = 20.6$. To explain the large range of observed apparent speeds (see Figure 1) as an effect of spatial jet bending, a Lorentz factor of $\gamma > 15$ and a viewing angle of the VLBI jet of $\theta < 2^\circ$ are more likely. Under these circumstances, the Doppler factor would be $\delta > 30$.

Such high Doppler factors are in good agreement with those derived from intrinsic intraday variability at cm-wavelengths, which are required to bring the high apparent brightness temperatures of up to 10^{17} K down to the inverse-Compton limit of 10^{12} K.

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References

- Britzen, S., et al. 1999, In ASP Conf. Ser. Vol. 159: BL Lac Phenomenon, ed. L.O. Takalo & A. Sillanpää, (San Francisco: ASP), 431
- Eckart, A., et al. 1986, A&A, 168, 17
- Eckart, A., et al. 1987, A&AS, 67, 121
- Gabuzda, D.C., et al. 1998, A&A, 333, 445
- Gabuzda, D.C., Pushkarev, A.B., & Cawthorne, T. V. 2000, MNRAS, 319, 1109
- Heeschen, et al. 1987, AJ, 94, 1493
- Jorstad, et al. 2001, ApJS, 134, 181
- Kellermann, K.I., et al. 1998, AJ, 115, 1295
- Quirrenbach, A., et al. 1991, ApJ, 372, L71
- Ros, E., et al. 2001, *a*, 376, 1090
- Schalinski, C.J., et al. 1992, in Variability of Blazars, ed. E. Valtaoja & M. Valtonen (Cambridge University press), 225
- Tian, W.W., et al. 2001, IAU Symposium 205, Galaxies and their Constituents at the Highest Angular Resolutions, Manchester, ed. R.T. Schilizzi, S.N. Vogel, F. Paresce & M.S. Elvis, 96
- Wagner, S.J., et al. 1996, AJ, 111, 2187
- Witzel, A., et al. 1986, Mitteilungen der Astronomische Gesellschaft, 65, 239
- Witzel, A., et al. 1988, A&A, 206, 245
- Zensus, J.A., et al. 2002, AJ, 124, 662